Modelling the wind farm wake for the Horns Rev photo case 2016

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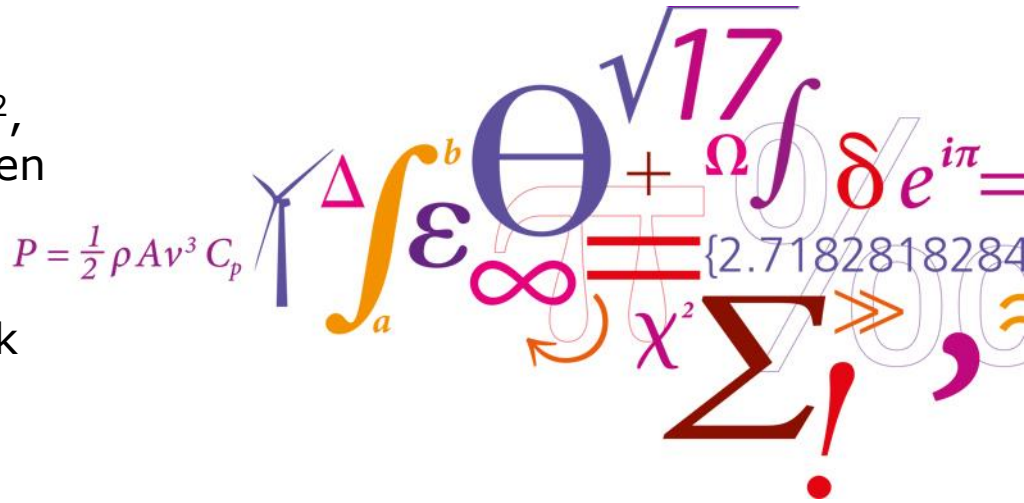


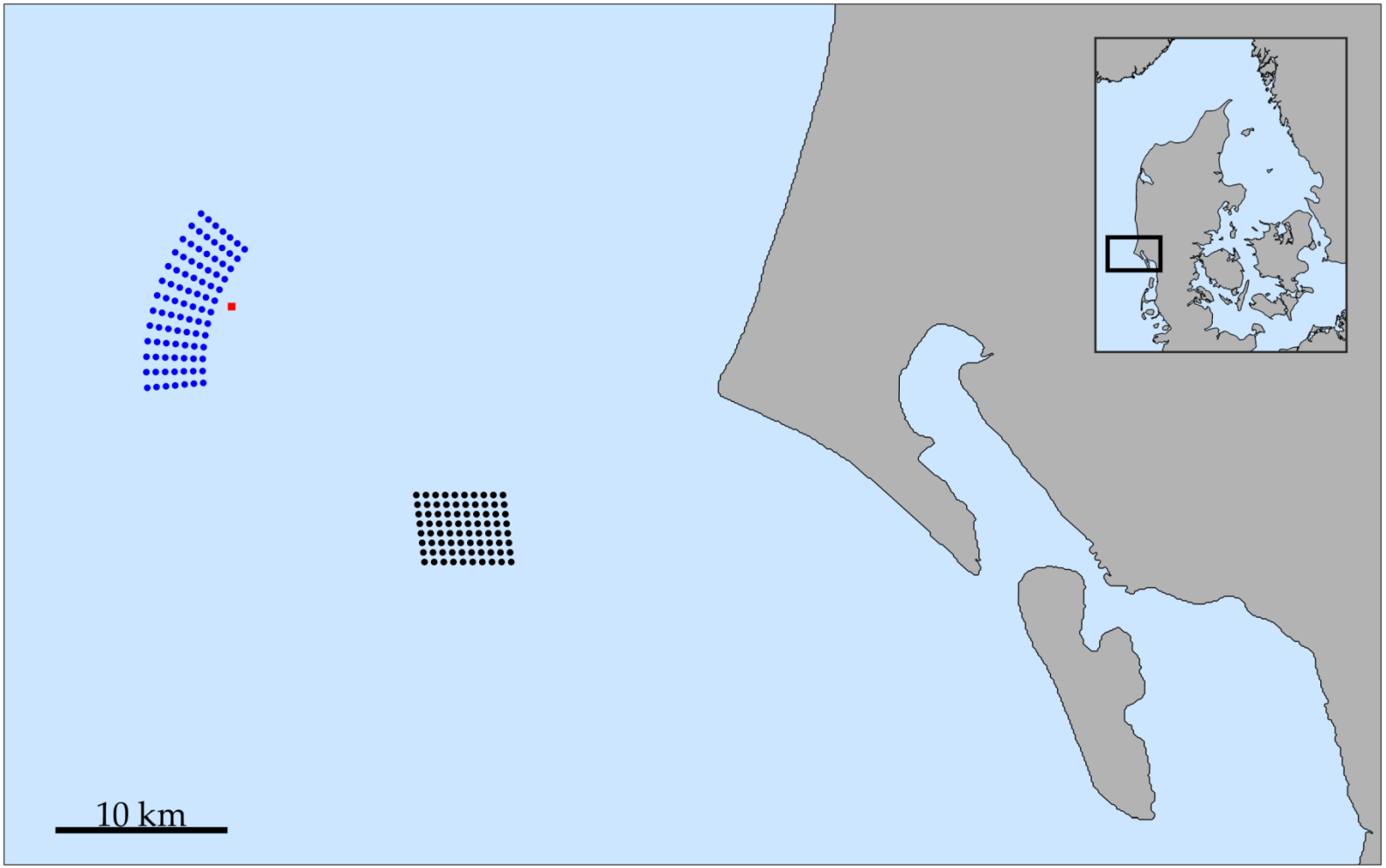
DTU Wind Energy
Department of Wind Energy

Wakes visualized at Horns Rev 1 in 2008

Unstable conditions. Low wind speed

Credit: Vattenfall. Photographer is Christian Steiness.

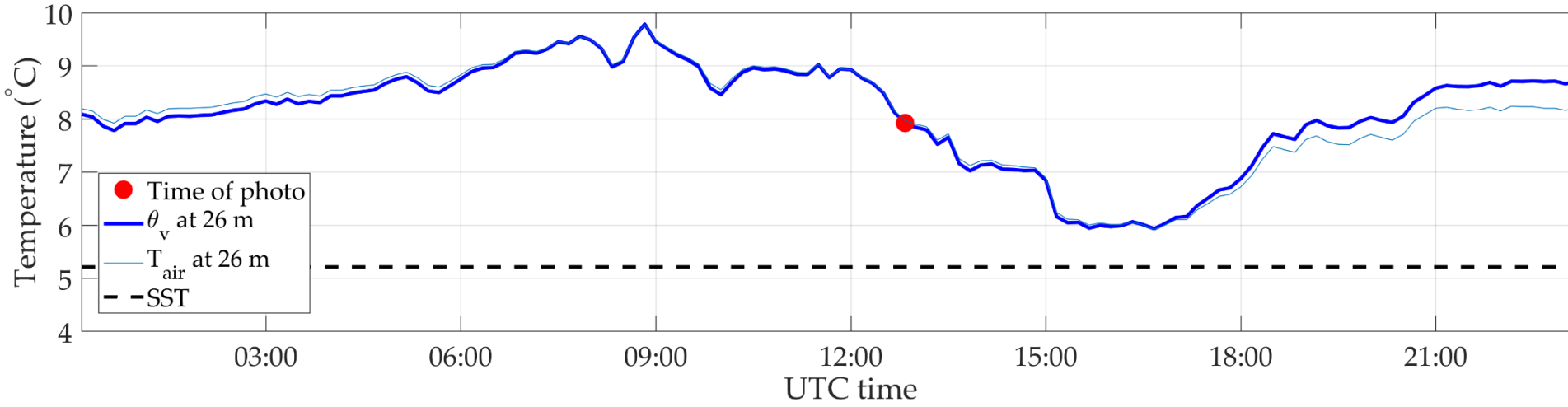
Location: Horns Rev 2

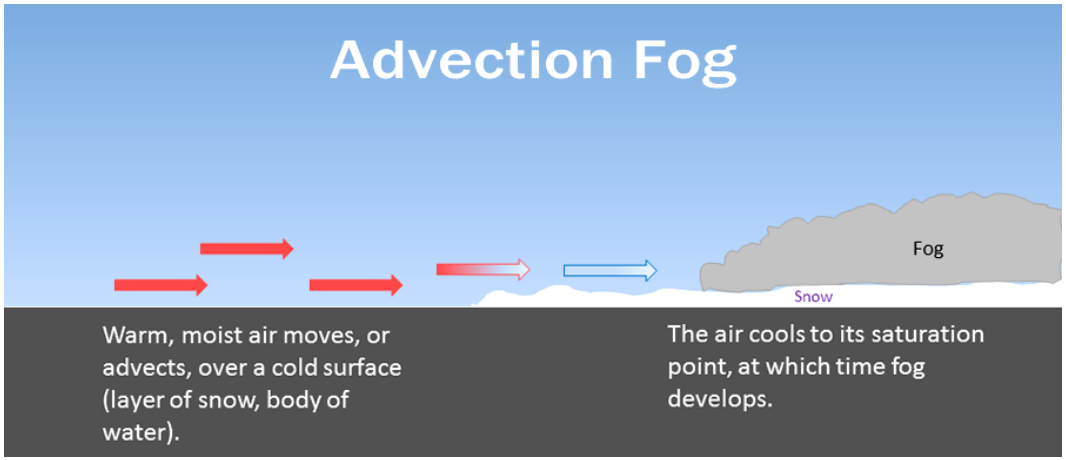


The situation

25 January 2016 12:45 UTC

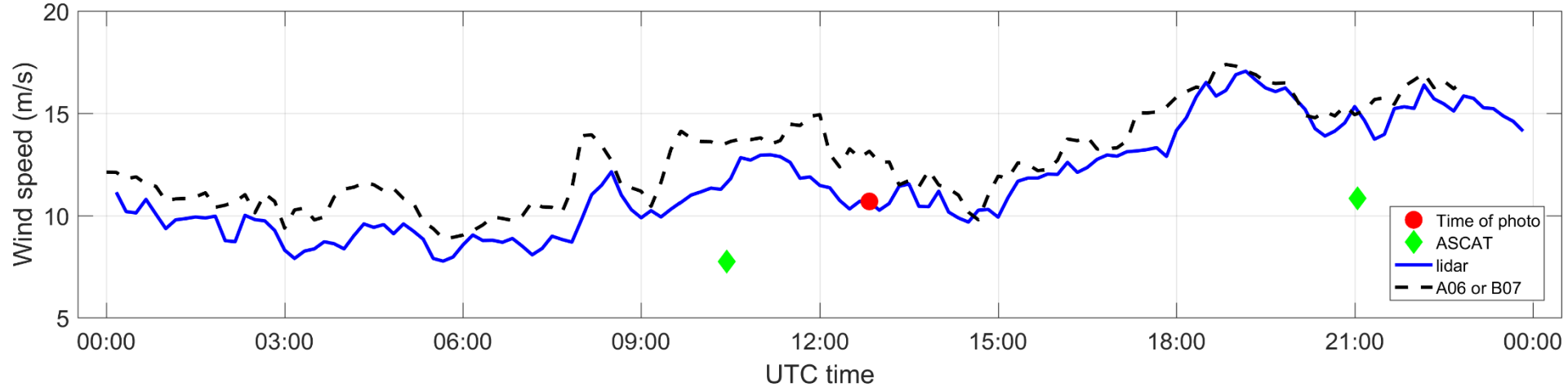
The atmospheric conditions





http://mrcc.isws.illinois.edu

The wind conditions



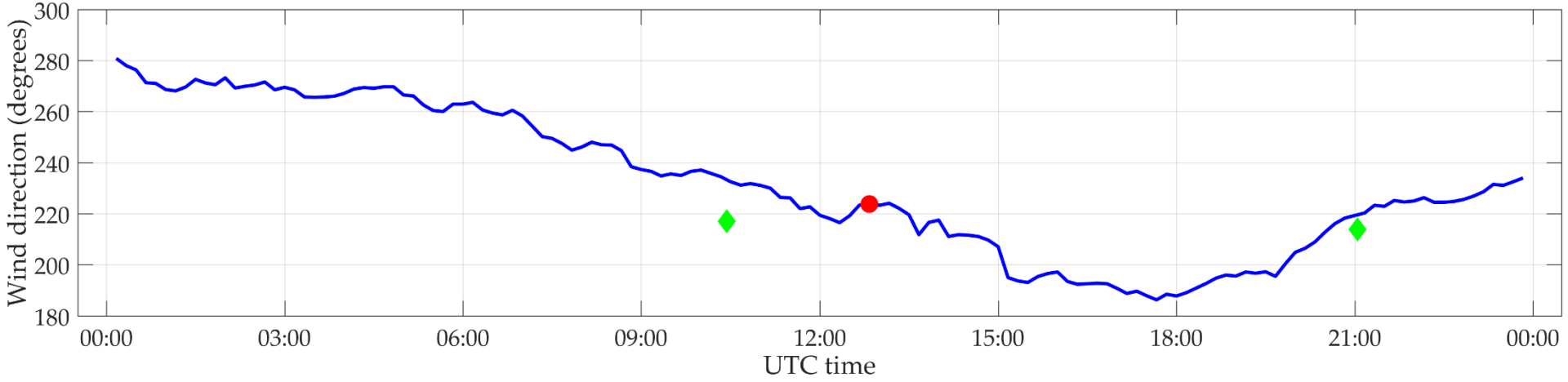



Photo by: Bel Air Aviation Denmark - Helicopter Services

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Questions

1. Do the fog trails correspond to the wakes?

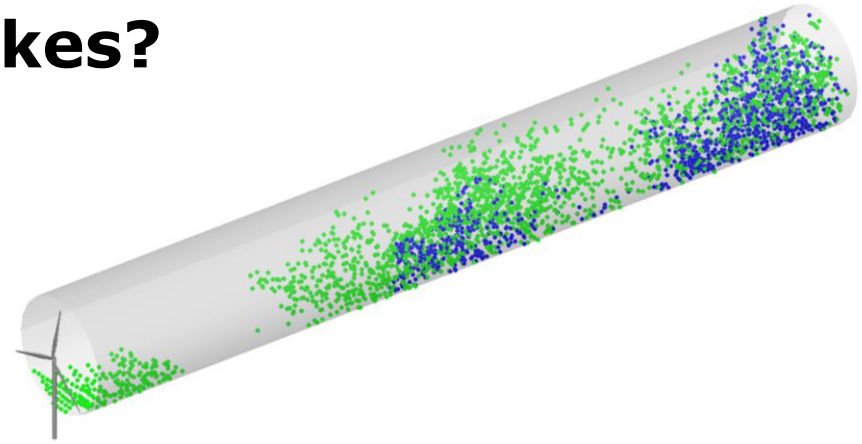
2. Why did fog end?

3. Do the visual wakes match the wind speed pattern?

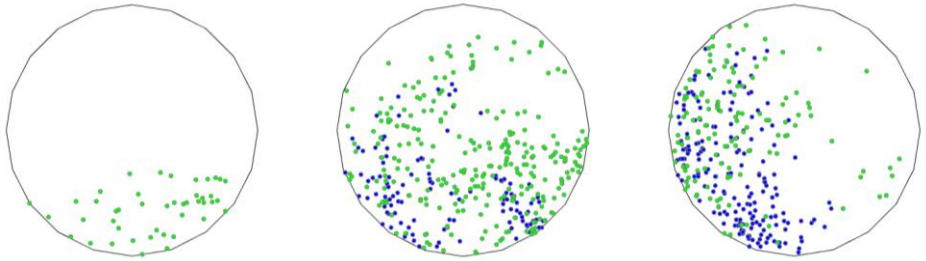
4. Does our wake model match the production pattern?

Fog trail = wakes?

LES
EllipSys3D

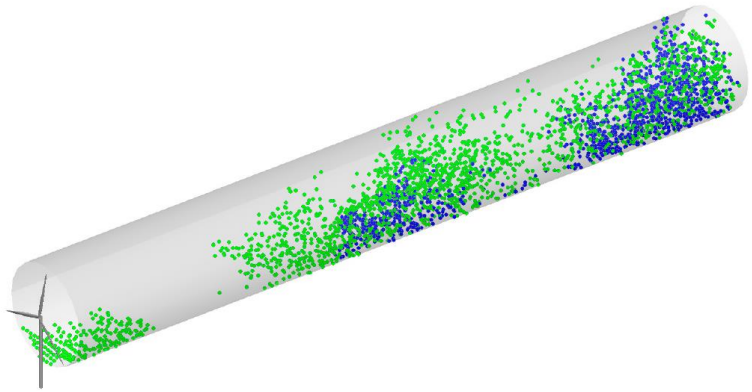


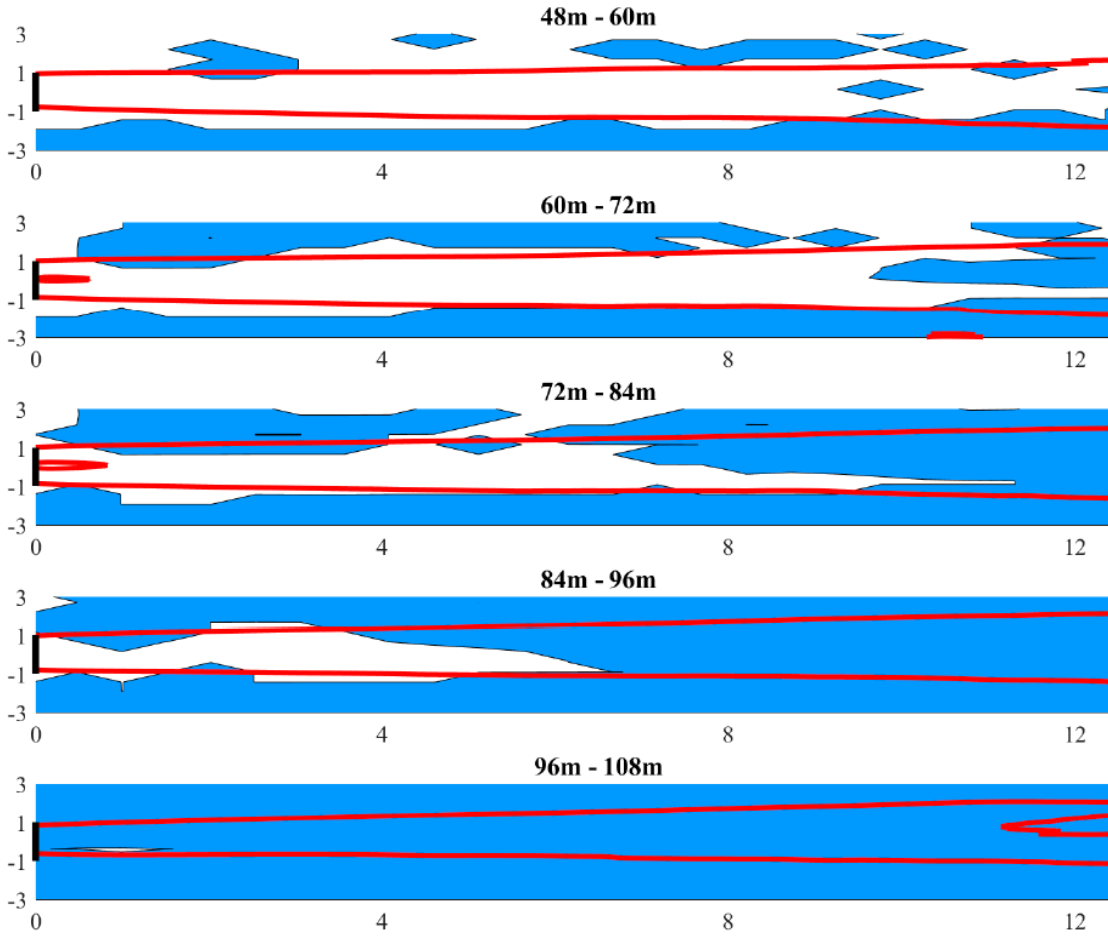
Visualization of wake development. Blue particles were initially released from Z = [0–0.46]R and green from Z = [0.46–0.96]R.



Particles located at sections at X = 3–5R, 7–9R, and 11–13R behind the turbine. Seen from behind.

Fog trail = wakes?



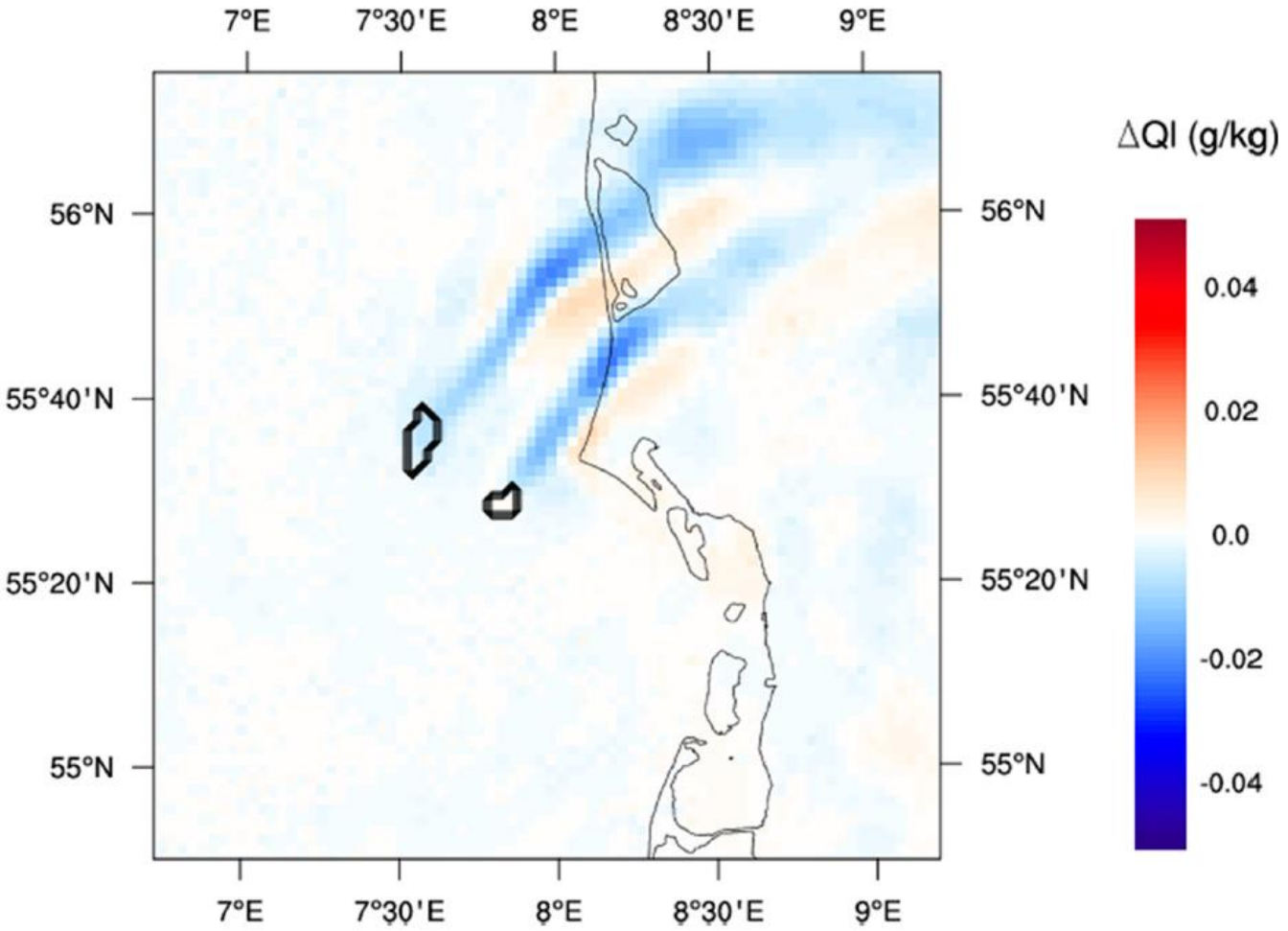


LES with particle tracking

Particles carry temperature

Average temperature sets fog/clear air

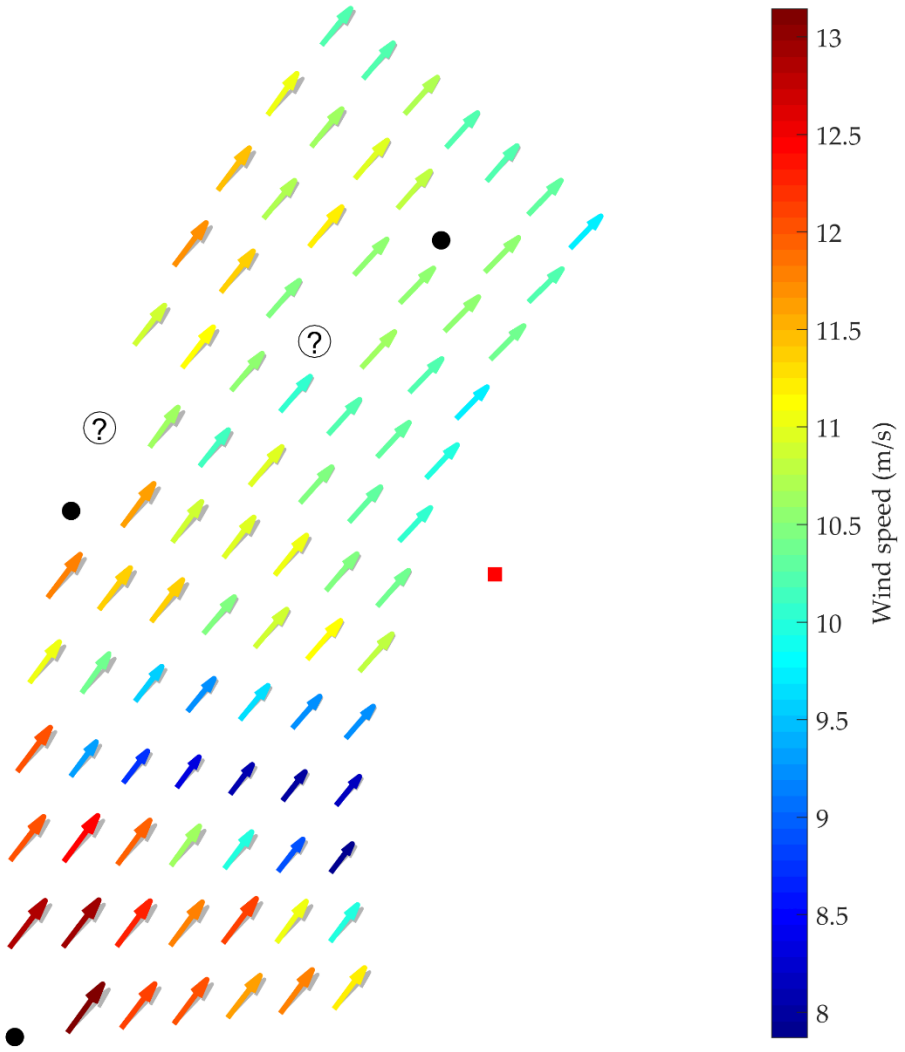
Why did the fog clear?



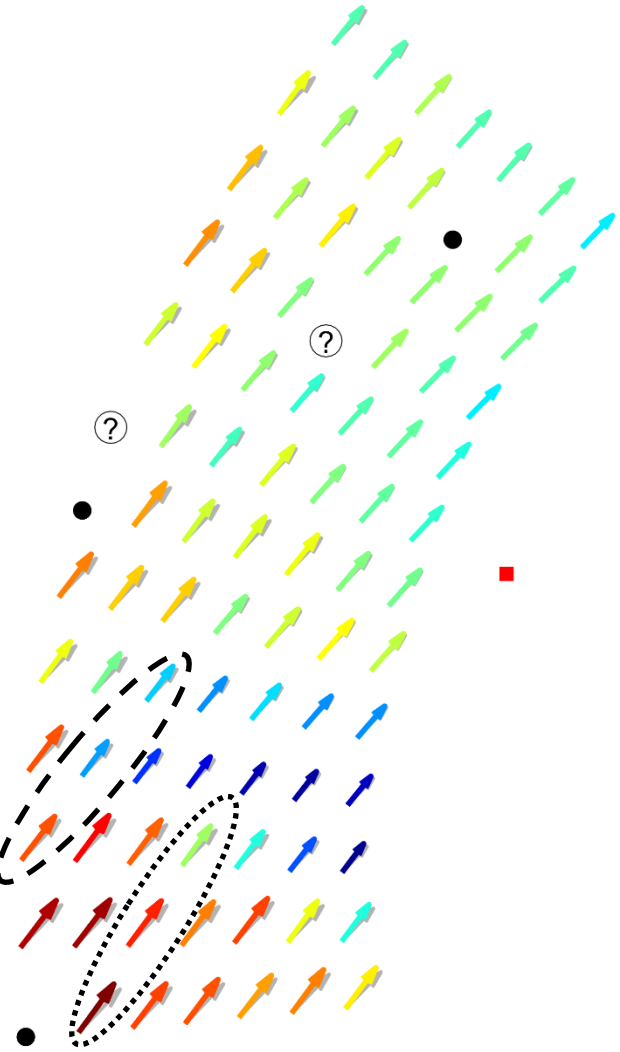
Difference in liquid water content due to wind farms

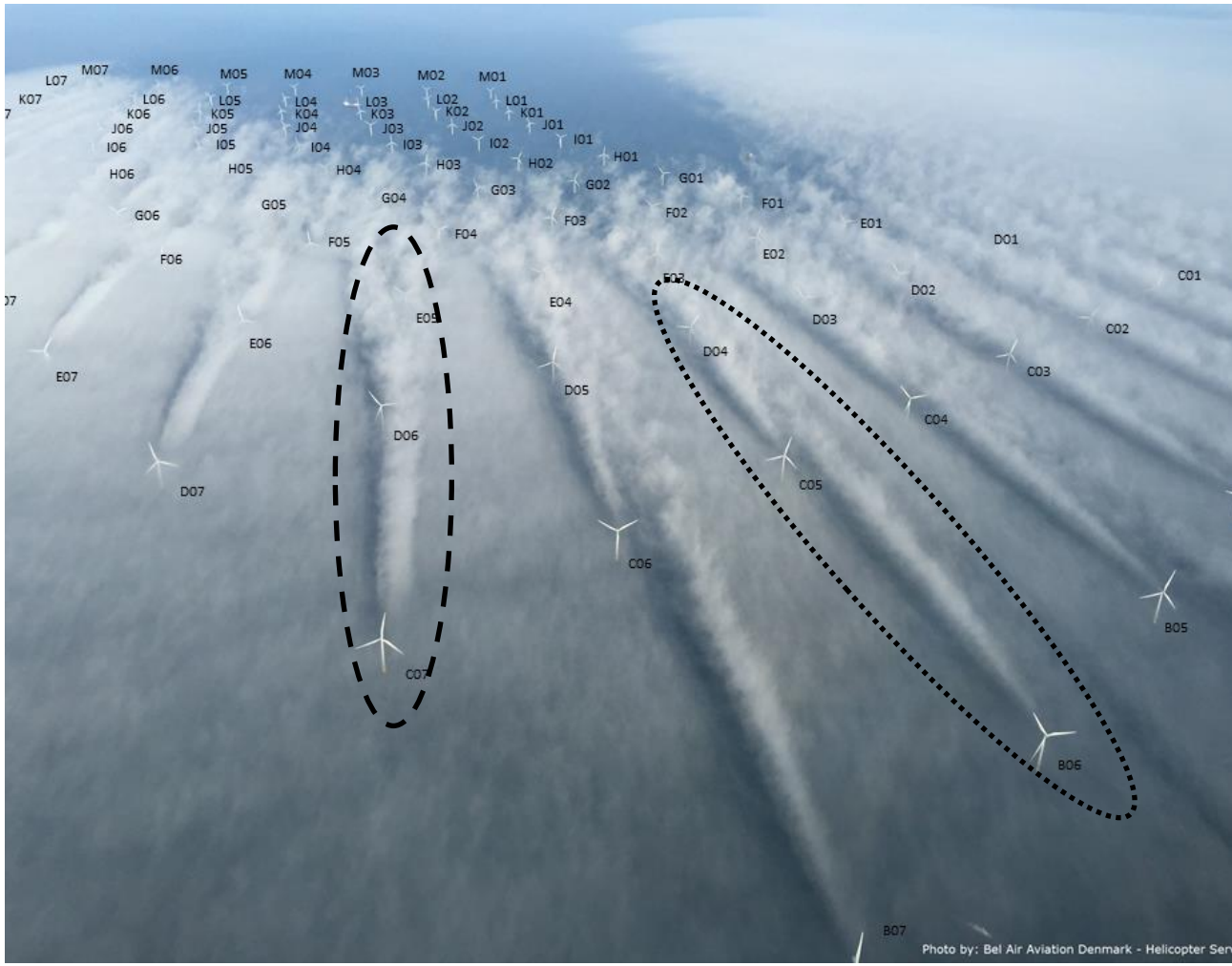
WRF simulations with and without wind farm shows dryer air at hub height behind wind farms

Wind speed pattern

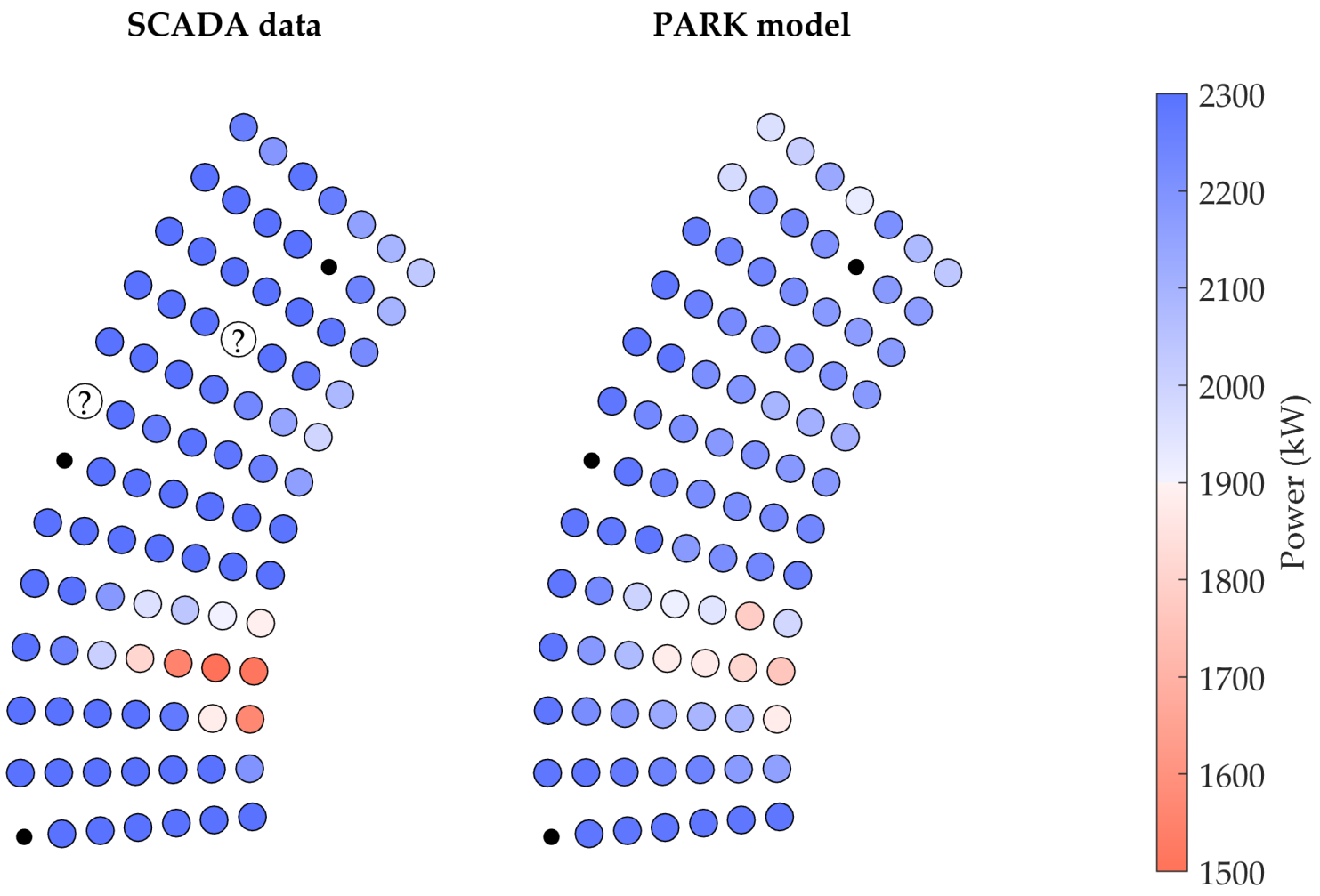


Wind speed pattern





Performance of wake model



Information	12 February 2008	25 January 2016
Wind farm name	Horns Rev 1	Horns Rev 2
Number of turbines	80	91
Rated production (kW)	2000	2300
Actual production (kW)	~80	~2300
Wind turbine status	Few turbines at cut-in	Most turbines at rated
Wind speed (m/s)	~4	~13
Wind direction (degrees)	~181	~223
Air temperature (°C)	~3.5	~8.0
Sea surface temperature (°C)	~5.0	~5.2
Turbulence intensity (%)	~17	~3
Atmospheric stability	Unstable	Stable
Wake expansion	Wide, looping	Narrow, fanning
Type of fog upstream	Warm water advection fog	Cold water advection fog
Near wake process	Condensation in high TKE	Saturation dew-point at low height
Far wake process	None	Dispersion due to mixing air aloft


Courtesy: Vattenfall

2008


Photo by: Bel Air Aviation - Helicopter Services

2016


Photo by: Bel Air Aviation Denmark - Helicopter Services

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Article

Wind Farm Wake: The 2016 Horns Rev Photo Case

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Companion papers

Horns Rev 1, 2008

Energies **2013**, *6*, 696-716; doi:10.3390/en6020696

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Article

Wind Farm Wake: The Horns Rev Photo Case

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Abstract: The aim of the paper is to examine the nowadays well-known wind farm wake photographs taken on 12 February 2008 at the offshore Horns Rev 1 wind farm. The meteorological conditions are described from observations from several satellite sensors quantifying clouds, surface wind vectors and sea surface temperature as well as ground-based information at and near the wind farm, including Supervisory Control and Data Acquisition (SCADA) data. The SCADA data reveal that the case of fog formation occurred 12 February 2008 on the 10:10 UTC. The fog formation is due to very special atmospheric conditions where a layer of cold humid air above a warmer sea surface re-condensates to fog in the wake of the turbines. The process is fed by warm humid air up-drafted from below in the counter-rotating swirl generated by the clock-wise rotating rotors. The condensation appears to take place primarily in the wake regions with relatively high axial velocities and high turbulent kinetic energy. The wind speed is near cut-in and most turbines produce very little power. The rotational pattern of spiraling bands produces the large-scale structure of the wake fog.

Horns Rev 2, 2016

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Article

Wind Farm Wake: The 2016 Horns Rev Photo Case

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Abstract: Offshore wind farm wakes were observed and photographed in foggy conditions at Horns Rev 2 on 25 January 2016 at 12:45 UTC. These new images show highly contrasting conditions regarding the wind speed, turbulence intensity, atmospheric stability, weather conditions and wind farm wake development as compared to the Horns Rev 1 photographs from 12 February 2008. The paper examines the atmospheric conditions from satellite images, radiosondes, lidar and wind turbine data and compares the observations to results from atmospheric meso-scale modelling and large eddy simulation. Key findings are that a humid and warm air mass was advected from the southwest over cold sea and the dew-point temperature was such that cold-water advection fog formed in a shallow layer. The flow was stably stratified and the freestream wind speed was 13 m/s at hub height, which means that most turbines produced at or near rated power. The wind direction was southwesterly and long, narrow wakes persisted several rotor diameters downwind of the wind turbines. Eventually mixing of warm air from aloft dispersed the fog in the far wake region of the wind farm.

Keywords: wind farm wake; fog; wake modelling; meteorological conditions

1. Introduction

As wind turbines extract energy from the wind, they leave regions of lower speed air in their wakes. For offshore wind farms, wakes are responsible for the largest single loss of energy production. Considerable effort is therefore being put to the analysis and modelling of wake effects [1–9]. Normally, the wakes are invisible, discernible only through the reduced production of downstream turbines caught in the wakes. But in recent years, wakes have been visualized and put under quantitative scrutiny (both onshore and offshore) through the deployment of remote sensing methods such as lidars [10–12], radars [13] and synthetic aperture radar [14,15].

However, direct visual observation of wakes in a wind farm remains rare. For this reason, two photographs taken on 12 February 2008 at the Horns Rev 1 offshore wind farm have become quite renowned, to the point where they have become the quintessential illustration of wind farm wakes. Even though the Horns Rev 1 photographs do not provide quantitative information about the flow field in the wakes, they do offer a dramatic illustration of the wake expansion, and of the turbulent nature of the flow in the wakes. Analysis of the images and of the meteorological conditions at the time revealed that the atmosphere was convective and that the wakes were captured by the re-condensation of fog. This process was triggered by the lifting and cooling of warm super-saturated air from the lower part of the rotor area by the swirling motion of the air in the wakes themselves [16,17]. The wind